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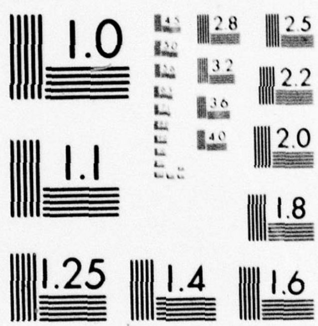
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OFFICE OF NAVAL RESEARCH

Contract NR 207-022

9 Annual ~~Report~~ No. 5, Jan 77—Jan 78,

6 Solid State Biology, Cellular Water Structure, and Ion Complexing with Application to Navy Medicine,

by

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Naval Air Development Center

Warminster, Pa. 18974

12 25p. 11 1 January 1978

Unclassified

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Abstract

Improved understanding of salt and water metabolism and of solid state physical processes in cells obtained in this project is directed toward the improvement of medical treatment of shock and of other salt and water disease processes, and toward the facilitation of the use of electromagnetic fields in healing of wounds and bone fractures. During 1977, this project emphasized applications, extensions, and development of new methodology relating to the Ling association-induction hypothesis of salt and water metabolism. Four new methods for detection of, and new evidence for the presence of, cooperative interactions and phase transitions in biological systems were developed. Evidence was obtained for the concept of Ling that cooperative interactions play important roles in the function of nerve and muscle. In addition, studies of melanin, the black pigment of eye, skin, and brain, have been performed, which suggest that this pigment may store packets of biological energy, and that cooperative interactions between conduction electrons may play a role in its switching behavior.

I. Introduction

This project is intended to provide improved understanding of salt and water metabolism and of solid state physical electron transport properties of cells, as foundations for improvements in medical treatments of shock and of other disturbances of tissue salt and water, and for improvements in electromagnetic methods of facilitation of healing of bone fractures and regeneration of amputated limbs.

During 1977, the work under this project emphasized applications, extensions, & development of new methodology relating to the Ling association-induction hypothesis (1), which, in the opinion of the present author, represents a correct general description of the salt and water biophysics of the cell. In the course of the above studies, four fundamentally new methods of biophysical analysis were developed (using simple graphical methods) which may have wide application for detection of cooperative interactions and phase transitions in many types of biological systems. In addition, some new experimental studies and concepts regarding the solid state biological functions of melanin were developed, which may relate to the presently unknown function of this black pigment in brain, eye and skin.

II. Salt and Water Metabolism. Extensions, Applications and Evidence for the Ling Association-Induction Hypothesis.

The Ling association-induction hypothesis represents a comprehensive theory of cell salt and water structure and function, which replaces the old concept of the cell liquid water contained in a membranous bag across which sodium and potassium ions are moved by cation pumps.

According to the Ling concept, cell water is structured and potassium and sodium cations are mostly associated with macromolecules. In the opinion of the present author, the evidence for this general picture is conclusive as recently reviewed (2).

During the past year, this project has concentrated on one particular aspect of the Ling association-induction hypothesis, namely on the concept of cooperative interactions and phase transitions in cell salt and water phenomena. Ling (1) has already emphasized the probable importance of these concepts to the general picture of the association-induction hypothesis, and has presented (3) experimental evidence for their role in cation association. Under the present project, Ling's work was confirmed and extended by providing additional evidence of cooperative interactions for cation association in muscle, and by evidence of cooperative interactions and phase transitions for contraction in muscle, for membrane potential and for potassium conductance in nerve, as well as for growth and photosynthesis. This evidence was provided by adaptation of solid state physical methodology. The result was simple, graphical techniques for detection of cooperative interactions by analysis of experimental data from biological systems.

The first new technique developed under this project is the use of Avrami plots (4,5) of sigmoid biological time curves taken from the theory of metallurgy. Examples are plots of Ling muscle potassium leakage data (fig. 1) and Hodgkin-Huxley nerve axon potassium conductance data (fig. 2), in which linearity indicates the occurance of a phase transition during these processes.

The second new technique is the analysis of non-linear Arrhenius plots to find the logarithm of the activation energy to be a linear function of temperature (6), which is observed in ferromagnetism and is therefore a probable indication of cooperative interactions. An example from this project is such a test on the resting membrane potential of nerve (fig. 3) in which linearity indicates a role for cooperative interactions.

The third new technique (6) is the application of critical exponent analysis of biological variables, which was taken from modern physics, but had not been used before in biology. A critical exponent plot of nerve membrane potential is shown in figure 4, in which linearity indicates again the participation of cooperative interactions in this biological process.

In addition to the above studies of cooperative interactions and phase transitions, solid state methods were used to confirm and extend Ling's concepts in two additional ways. First, experimental axon sodium repolarization currents were shown to conform to the Elovich equation, which implies that in the axon, sodium is associated, water is structured, and that an activation energy barrier to sodium conduction exists at the axon surface (7). Second, a solid state theory of competitive diffusion of associated sodium and potassium ions was developed, which allows one to determine whether cation diffusion in nerve or muscle is by a free cation or by a vacancy mechanism (8).

III. New Biophysical Methods of Analysis Developed under This Project During 1977. Four new methods were introduced. All are simple to understand and easy to apply to biological data. They are:

1. Avrami plots of sigmoid biological time curves for detection of cooperative interactions or phase transitions in biological systems (4,5).
2. Critical exponent analysis of biological variables for phase transactions (6).
3. Critical exponent analysis of activation energies from nonlinear Arrhenius plots of biological data for detection of cooperative interactions (9).
4. Linearity of the logarithm of activation energy vs. temperature from non-linear Arrhenius plots of biological data as an indication of cooperative interactions (6).

IV. Solid State Biological Properties and Functions of Melanin.

Melanin is the black pigment which occurs as particles in the substantia nigra of the brain, in the eye and in skin. Its physiological function is at present unknown. Under this project, melanin was measured to have an infra-red phosphorescence in the 3 micron region of wavelength, persisting 4 to 8 seconds (5). Because a photon of this wavelength has an energy like that of the terminal phosphate of ATP, this observation suggests that melanin may function as an alternative method for storing packets biological energy (5). Melanin has been shown by others (10,11) to have electrical switching behavior like amorphous inorganic semiconductors, which was confirmed by experimental studies under the present project. Under the present project, a role for cooperative interactions

between conduction electrons in this process was suggested by the application of Method 3 of the last section to some data on an amorphous semiconductor (9), and by the possibility that switching might occur by inversion of an emulsion of aggregated electrons (12).

V. Publications

Nine articles have been written in 1977 describing the work done under this project (2,4,5,6,7,8,9,12,13).

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Captions for Figures

Figure 1 - Avrami Plot of K^+ Leakage from Poisoned Muscle.

Experimental data is from Ling and Bohr (3). This plot is taken from reference 5. (1 - X) is the fraction of K^+ concentration in frog muscle at times after the start of incubation with iodoacetamide.

Figure 2 - Avrami Plot of Hodgkin - Huxley Data on Axon K^+ Conductance.

This plot is taken from reference 4. Points represent Hodgkin - Huxley measurements of axon potassium conductance at times after abrupt depolarization. X is the fraction of maximum K^+ conductance measured at times after the onset of axon depolarization.

Figure 3 - Nerve Membrane Log of Activation Energy (E_a) vs. Temperature Plot. This plot is taken from reference 6. Linearity shows that nerve membrane behaves like a ferromagnetic material, which implies the presence of cooperative interactions. Values of E_a were obtained from slopes of the non-linear Arrhenius plot of the experimental data for resting membrane potential as a function of temperature (6).

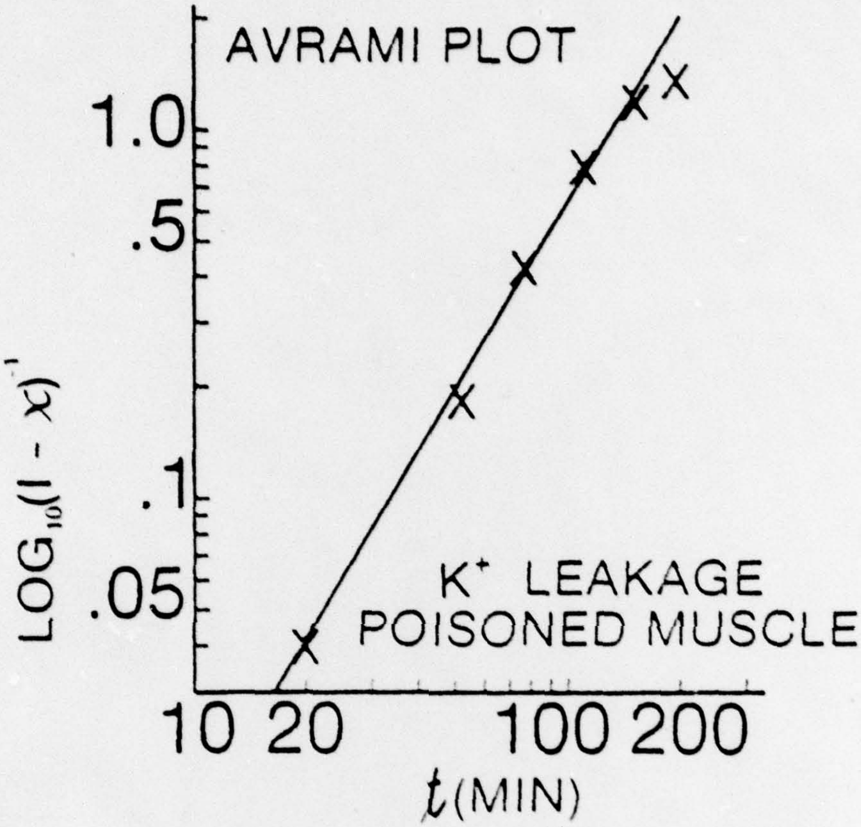

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Figure 1

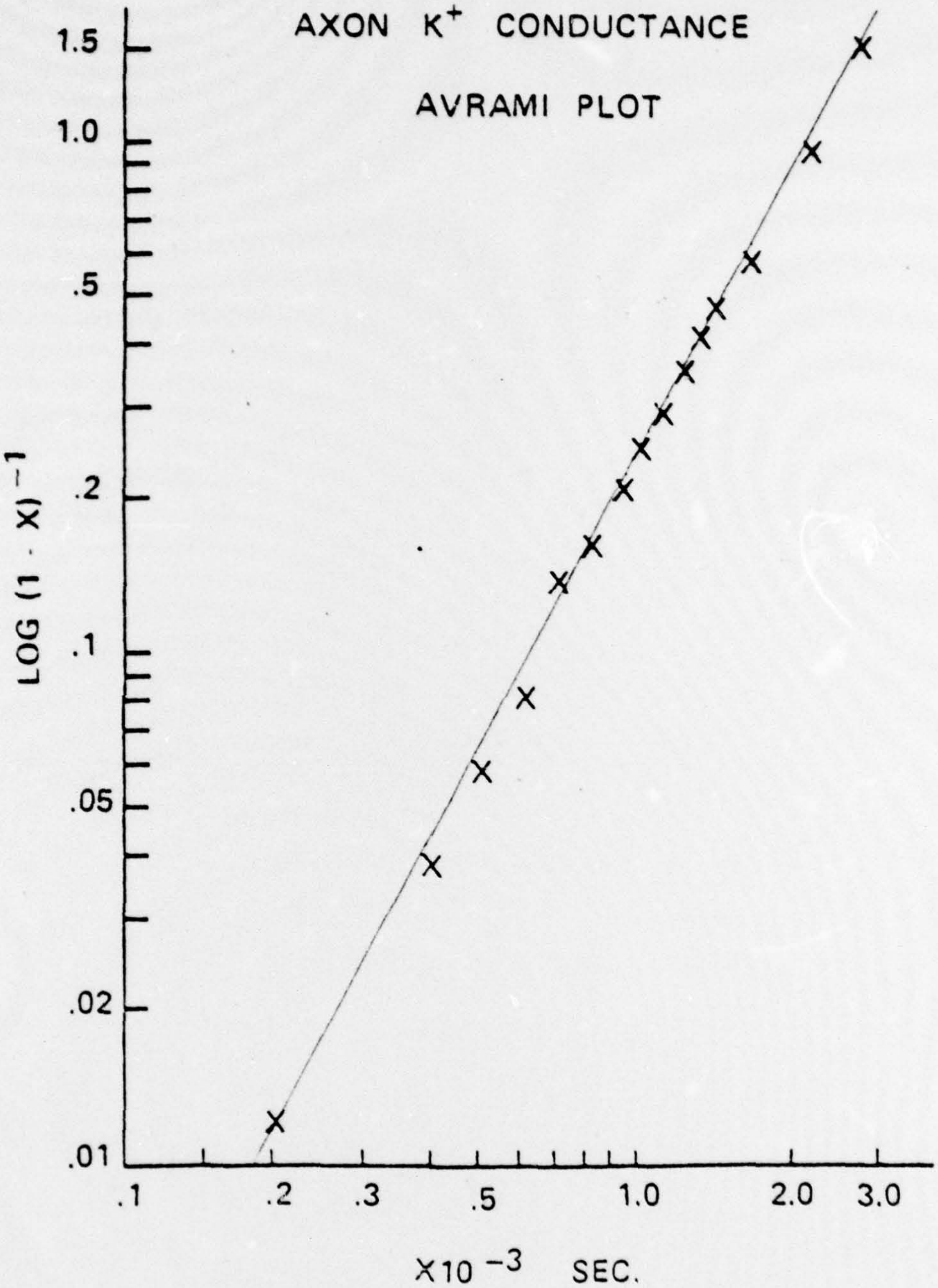
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Figure 2

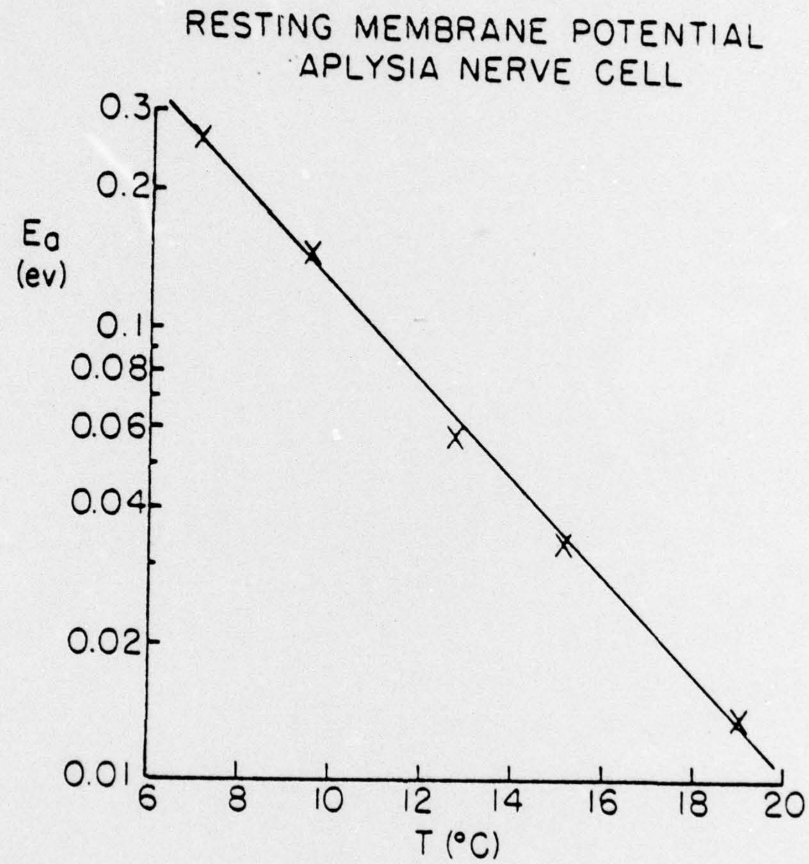
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Figure 3

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Naval Air Development Center
Warminster, Pa. 18974

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
Solid State Biology, Cellular Water Structure, and Ion Complexing with Application to Navy Medicine

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Annual Report (Jan 1977 - Jan 1978

5. AUTHOR(S) (First name, middle initial, last name)
Freeman W. Cope

6. REPORT DATE
1 Jan 1978

7a. TOTAL NO. OF PAGES
11

7b. NO. OF REFS
15

8a. CONTRACT OR GRANT NO.
ONR Contract NR 207-022

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
#5

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Distribution of this report is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Office of Naval Research
Biophysics Program, Code 444
Arlington, Virginia 22217

13. ABSTRACT

Improved understanding of salt and water metabolism and of solid state physical processes in cells obtained in this project is directed toward the improvement of medical treatment of shock and of other salt and water disease processes, and toward the facilitation of the use of electromagnetic fields in healing of wounds and bone fractures. During 1977, this project emphasized applications, extensions, and development of new methodology relating to the Ling association-induction hypothesis of salt and water metabolism. Four new methods for detection of, and new evidence for the presence of, cooperative interactions and phase transitions in biological systems were developed. Evidence was obtained for the concept of Ling that co-operative interactions play important roles in the function of nerve and muscle. In addition, studies of melanin, the black pigment of eye, skin, and brain, have been performed, which suggest that this pigment may store packets of biological energy, and that cooperative interactions between conduction electrons may play a role in its switching behavior.

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Biological Water Nuclear magnetic resonance Biological potassium Biological ion transport Blood loss shock						

DD FORM 1 NOV 65 1473 (BACK)

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